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Dated 27 September 2004

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200CT03 E845805-1 B17284
P01/7700 0.00-0324439.9

1/77

20 OCT 2003

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

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1. Your reference

2. Patent application number
(The Patent Office will fill this part in)

0324439.9

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

GIDEON R. LEVINGSTON
50 AVENUE FRANCIS DE CROISSET
06130 GRASSE
FRANCE

Patents ADP number *(if you know it)*

0873698500I

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention MINIMAL THERMAL VARIATION AND TEMPERATURE COMPENSATING NON-MAGNETIC BALANCE WHEELS AND METHODS OF PRODUCTION OF THESE AND THEIR ASSOCIATED BALANCE SPRINGS FOR A PRECISION MECHANICAL OSCILLATOR SYSTEM.

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

24 LANCASHIRE ROAD
BISHOPSTON
BRISTOL
BS7 9DL

Patents ADP number *(if you know it)*

0873703300I

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute (see note f)

Number of earlier UK application	Date of filing *(day / month / year)*

8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request?
Answer YES if:
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
Otherwise answer NO (See note d)

NO

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form:

Continuation sheets of this form	
Description	16
Claim(s)	
Abstract	
Drawing(s)	3 + 3 = 6

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent (Patents Form 7/77)	
Request for a preliminary examination and search (Patents Form 9/77)	
Request for a substantive examination (Patents Form 10/77)	
Any other documents (please specify)	

11. I/We request the grant of a patent on the basis of this application.

Signature(s) Gideon Levingston . .   Date 16th/10/03

12. Name, daytime telephone number and e-mail address, if any, of person to contact in the United Kingdom   SIMON LEVINGSTON 0117 902 2768 gideon.levingston@wanadoo.fr

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Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.

b) Write your answers in capital letters using black ink or you may type them.

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f) Part 7 should only be completed when a divisional application is being made under section 15(4), or when an application is being made under section 8(3), 12(6) or 37(4) following an entitlement dispute. By completing part 7 you are requesting that this application takes the same filing date as an earlier UK application. If you want the new application to have the same priority date(s) as the earlier UK application, you should also complete part 6 with the priority details.

Balance Wheel for Mechanical Oscillator System

The present invention relates to a balance wheel for use in precision horological timekeeping mechanical oscillator systems, or in other precision instruments. It is thought that it will be particularly applicable to the oscillator system in a mechanical watch although the present invention is not limited to this.

Balance wheels for watches have previously been principally made of metal. A balance spring is arranged to oscillate the balance wheel and to do so with a period of oscillation that should be isochronous.

The metals used have generally high linear expansion coefficients as compared to most ceramics. Whereas this has been the norm for example in the systems containing a balance wheel made of metal (Fe-Ni, Cu-Be, Cu-Zn, Cu-Au, Ni or combinations of these) and the balance spring made from an Fe-Ni alloy, or Fe-Mn-C or other steel derivative alloys, new balance spring materials enable the thermal and magnetic influences in this relationship to be improved or overcome, and thus greater precision to be reached.

The effects of thermal influences upon the balance wheel and the balance spring are not the same. The thermal and thermo-elastic characteristics within the relationship between the balance wheel and balance spring do not evolve in an identical manner.

The most successful attempts (C.E.Guillaume's, bi-metalllic compensating balance wheel and steel balance spring system invented 1912, Hamilton's, precision ferro-nickel based spring

alloy in conjunction with steel and invar ovalising balance wheel invented 1943) to bring the terms of the associating relationship into constancy have required the use of materials which despite their useful thermal characteristics (the ferro-nickel alloys have an abnormal Young's modulus evolution) are sensitive to magnetism, and this latter influence disturbs the Young's modulus stability and causes negative effects to the precision (isochronism) of the timekeeper.

The expression for the period of oscillation *T* is described as follows:

$$T = 2\pi\sqrt{\frac{I}{G}} \qquad [1]$$

T: the period of oscillation, *I*: the moment of inertia of the balance wheel, *G*: the torque of the balance spring.

The oscillator system is subject to variations of magnetic and thermal nature. When a balance wheel is made of metal it expands with an increase in temperature. The balance spring that is made most generally of a ferro-nickel alloy also expands with an increase in temperature.

The rates of linear expansion are measured in units of 1/1000 of millimeters / degree Kelvin , represented for example in the case of copper, Cu, as $+17\times10^{-6}/K^{-1}$ and are known as the α coefficient.

The thermoelastic coefficient describes the tendency of change in elasticity of the material for a rise in temperature.

The ferro-nickel alloy has a positive thermoelastic coefficient which is described as 'abnormal', up to 40°C when fully de-magnetised. Magnetic accumulation however lowers this threshold which causes the divergence of terms *E* and *r* at lower

temperature (1), and is the cause of the resultant error in the isochronism of the oscillator.

Whereas the balance wheel is in general only affected by thermal variations, which affect its physical dimensions, the balance spring is affected by both thermal and magnetic variations, which affect both its physical dimensions, and its elasticity (Young's modulus).

For the improved performance of the timekeeper these negative effects must be eliminated or reduced to a minimum. The inventor has noticed that the Young's modulus of balance springs and the Fe-Ni balance spring in particular are affected by temperature and magnetism, and that the magnetic accumulation in the spring has a detrimental effect on timekeeping. The changes in the spring account for the major part (75%) of the oscillator error, much of the remaining error is due to thermally induced changes in the balance wheel.

The variables contained within relationship [1] are expressed:

$$T = 2\pi\sqrt{\frac{12.M.r^2 l}{E.h.e^3}} \qquad [2]$$

Temperature and magnetic variations influence T (the period of oscillation) resulting from the effects of expansion and contraction of the balance spring and balance wheel and the changes in elasticity of the spring material.

The torque of the balance spring is a function of its dimensions: length l, height h, thickness e, and of its Young's Modulus E.

The moment of inertia I of the balance wheel is a function of its radius r, and its mass M (which remains constant), and is expressed:

$T = M.r^2$ [3]

E the Young's modulus coefficient, changes with variations in temperature and magnetic influence.

Where a non magnetically sensitive and thermically stable balance spring has been selected with a linear thermo-elastic evolution in the operating temperature range (0-40°C), the thermally induced changes remaining to be resolved reside in the balance wheel.

This is only possible if the correct material choice is made for the balance wheel, and a correct understanding of its kinetic performance, and its static and dynamic poising and adjustment are understood and allowed for in its manufacture and regulating once in the timekeeper.

The variables within the equation which are affected by temperature changes which must now be brought into constant relation can be simplified and represented in the following expression:

$r/\sqrt{E}$ or r^2/E [4]

Radius of giration of the balance, r. The Young's Modulus of the spring E.

The expression for the relationship between radius of giration and the Young's modulus of the spring of materials used so far in the mechanical oscillator system is as expressed in [4]. These terms are not in a linear relationship, however it is necessary that this relationship should be constant (so as to keep the period T of oscillations isochronous).

The residual compensation that the balance must achieve, must be calculated as a function of the thermal expansion or

contraction of r, the mass is unaffected by changes in temperature. The moment of inertia being the product of $M.r$ expressed in [3].

Historically metal balance spring alloys have had a non-linear modulation of their thermoelastic modulus (the change in the Young's Modulus with a temperature change is described by the curve $\sqrt{E}$). As balance wheels made of a single metal have a linear increase in their value of r over a rise in temperature, the superimposed curves of the evolution of r and $\sqrt{E}$ with temperature plotted on the same graph show an intersection at two points where the values of δE provide a solution to the value of δr , or where the curved line of the graphed values of $\sqrt{E}$ intersects the straight line r). The discrepancy between the two curves at their widest separation is known as middle temperature error (2).

The balance wheels and balance springs in the past capable of resolving this problem have been made of magnetically sensitive materials and due to current levels of magnetic pollution, are no longer suitable.

To provide a solution to the relation $\frac{r}{\sqrt{E}}$, first a spring with a linear thermoelastic evolution is required, where the characteristics of the spring allow a constant evolution so that the relationship becomes r/E, and where the α coefficient of axial expansion of the spring for a rise in temperature is negative.

In order to improve the performance of the system having made the correct choice of spring, such as the inventor has devised, the choice of materials for the balance wheel must be for those

insensitive to magnetism, most preferably of low α coefficient, and if not of the same sign then of very low α coefficient of opposite sign to the axial α coefficient of the spring material, which should preferably be of linear and low thermoelastic modulus tendency < 1% between 0 and 80°C, (3). Most preferably the balance wheel material should be of α coefficient of the same sign as the thermoelastic Modulus tendency of the spring.

The α coefficients and the expansion characteristics whether isotropic or anisotropic, and the Young's Modulus must all be calculated and considered carefully in the relationship [2]. If any of the variables are ignored, or the manner in which they are implicated in the system in motion, is done so without reference to, and understanding of, the other variables and their inter-relationship, no improved performance will be gained.

In general, the formula for timekeeping changes (U) consequent upon a rise in temperature of 1°C is

$$U = \alpha_1 - 3\alpha_2 / 2 - \delta E / 2E \qquad [5]$$

Thus U can be made to tend to zero when suitable values of α_1 the balance coefficient of thermal expansion, and α_2 the balance spring coefficient of thermal expansion, and the thermoelastic coefficient E are selected by careful choice of appropriate materials.

For a selected balance spring material where the thermoelastic modulus varies in a linear manner in the ambient range and is minimal, and where the spring requires the balance for its part to compensate in a residual manner in a positive or negative sense, the following solutions are proposed.

The present invention relates to the balance wheel of a mechanical oscillator system composed of balance wheel and balance spring, wherein the balance wheel is preferably composed wholly of, or a combination of non-magnetically sensitive and preferably but not exclusively low α coefficient materials ($<+6\times10^{-6}/K^{-1}$)including, ceramic material preferably from the group; aluminium nitride, alumino-silicate glass, alumina silica boria, boron carbide, boron nitride, silica, silicon, silicon dioxide, silicon nitride, zirconia (stabilised), potassium alumina muscovite, aluminium oxide (including ruby and sapphire) or diamond or synthetically derived diamond or extruded or isostatically moulded graphite, or thermoset, thermoplastic polymer or monomer, glass, carbon, or glassy carbon. Alternatively the materials may be chosen from the group of non-magnetically sensitive intermetallic compounds. The chosen materials may be in the form of fibres or nano particles continuous or dispered, in matrices of thermoset or thermoplastic polymer, ceramic, glass, carbon, or glassy carbon. Furthermore the materials may be in the form of powders or micropowders or microspheres which are hot pressed or reaction bonded, or tape casting material, which is preferably ceramic, in binders which may be of volatile, waterbased or polymeric substance. Furthermore the material may be a composite material composed of graphitic continuous carbon fibre or non-continuous carbon fibre, carbon nano-fibre or tube, polymeric or ceramic fibres in matrices of thermoset or thermoplastic polymer, ceramic, glass, carbon, or glassy carbon.

In order that such variation as is imposed by the thermal influences upon the balance wheel should be kept to a minimum.

In the first instance it is proposed that the materials selection for the balance wheel should preferably be for a low

α coefficient isotropic ceramic material for example fused quartz (silicon dioxide 96-99%), of a single phase crystalline or mixed phase crystalline and residual glass composition, which has an α coefficient of, $< +1.0 \times 10^{-6}/K^{-1}$. This ensures a limited evolution of r with temperature.

The balance wheel may preferably be circular and disc-like but is not limited to being circular. It may be formed with or without the additional mass of a perpendicular projecting shallow rim at the periphery. The upper surface plane which may preferably be circular and lower surface plane which may preferably be circular are parallel (figure 4).

A plain balance wheel or balance wheel and balance staff integrally fabricated of preferably one isotropic material composition with a low $+\alpha$ coefficient and incorporating poising and timing appendages integrated in the balance weights.

The balance wheel should preferably be disposed of identical appendages circumferentially fixed at the same radius from the central axis of rotation of the balance wheel (figure 4), at equal circumferential distance apart, the appendages to number no less than two, and up to as many as may form a continuous ring of equally spaced such appendages arranged close to the rim of the balance wheel (figure 4). Each appendage is so placed and so shaped as to allow for an equal distribution of its mass with an increase in temperature, from its centre point, and most preferably equally and in the circular plane of the appendage which is parallel with the plane of rotation of the balance wheel.

The appendages are composed of material of the same or greater density than the balance wheel itself, and allow for the moment

of inertia represented by $M.r$, to be determined and also for the static and dynamic poising of the balance wheel as is known in the preparation of precision watches and other instruments.

As such the appendages may be of metal or non-metal non-magnetically sensitive material which allow for the usual punctual removal of small amounts of the material for the purposes of the static poising of the balance wheel as is known in the art of regulating precision timekeepers.

Furthermore the appendages are furnished with the ability to increase or reduce the product of $M.r$ by reducing or increasing the effective radius of the centre of mass of part of or all the appendage in relation to the central axis of rotation of the balance wheel. This feature is required in adjusting the frequency of the balance for a 'free-sprung' oscillator system (a system not requiring curb pins to control the length of the spring and thus the frequency of the balance wheel period).

Historically this has been performed by timing screws mounted radially in the balance rim, in this case either by timing screws (6) or timing weights and or screw assemblies (5) or eccentric weights or screws (7) preferably incorporated into the individual appendage assembly. These may be situated in the axis either parallel to (figure 4) or perpendicular to (figure 3) or both parallel and perpendicular to (figure 5) the balance staff axis and are fixed either close to the edge of the plain balance wheel, or on the rim of the balance wheel, or on the crossmember and rim of whatever configuration.

The appendages and timing screw heads are so formed as to be of aero-dynamic profile so as to reduce the drag coefficient (5),(6).

This balance wheel can compensate for the effectof a low linear positive evolution of the thermoelastic modulus (E).

In the second instance where the balance spring is of 'normal' ($-E$), negative thermoelastic tendency, which is linear, then to resolve temperature error it is expedient to have a product of $M.r$ which decreases with a rise in temperature. The effect of reduced elasticity of the balance spring will be compensated by a reduction in the moment of inertia, and T (the period of oscillation of the balance wheel) will remain unaffected (4).

This may preferably be achieved in two ways.
The first of these is in the use of a combination materials for the balance wheel wherein a single or multiple membered sufficiently rigid balance wheel arm is made from a non magnetic material with $+\alpha$ thermal coefficient available from the appropriate materials previously listed, such that for an increase in temperature the cross member or members will extend (8). Their length will increase causing the less rigid balance rim (9) to deflect inwards.

The balance wheel rim is attached to the cross member or members at equally spaced intervals and is preferably composed of a non-magnetic sufficiently flexible material with a negative ($-\alpha$) linear thermal coefficient, preferably of greater magnitude than the positive ($+\alpha$) linear thermal coefficient of the cross member or members, and available in the materials previously listed and including continuous carbon fibre, polyaramid fibre and liquid crystal polyester or polyester/amide copolymer. Therefore for an increase in temperature the circumference of the balance wheel rim will decrease and being sufficiently flexible permit the inwards

deflection of the balance wheel rim at the midway point between its attachment to the cross member (12).

The same effect may also be achieved by the use of a balance wheel cross member or members of preferably negative ($-\alpha$) linear thermal coefficient and a balance wheel rim of positive ($+\alpha$) linear thermal coefficient of preferably greater magnitude composed of concave balance wheel rim segments of 45°-180° of arc (10). The ends of the concave segments of the rim are attached at equal radius from the centre of rotation, to the cross member or members (11). The positive linear expansion of the rim segments with a rise in temperature causes the centre of the arc to move toward the centre of rotation (12). The mass appendages fixed at the centre of the inverted arc rim segments are therefore carried towards the centre of rotation.

As a result of these last two configurations the effective radius r will decrease and therefore the product of $M.r$ will decrease. The mass appendages for poising and timing arranged in equipoise on the balance rim with a given product $M.r$ at temperature X°C move toward the centre of rotation simultaneously with a rise in temperature such that the product will become $M(r-n)$ at X+n°C.

Adjusting the relative position and size and number of the appendages on the balance wheel rim will allow for the accurate determining of the evolution of the product $M.r$ as the rate of change of radius is not the same at all points on the arcs or inverted arcs of the balance wheel rim between the points where they are attached to the balance wheel cross member.

With a suitable choice and combination of chosen materials the mass M multiplied by the negative rate of change δr or positive δr in the case of the the inverted curve rim, for a given rise

in temperature annuls the effect of the negative tendency of the thermoelastic modulus of the balance spring and the residual temperature error is resolved (4).

The timing screws oriented in the radial direction may be so shaped as to facilitate the engagement and disengagement of a specially shaped tool for the purpose of the precision adjusting the *M.r* product (13).

The timing screw appendages (14) may be disposed of indexes to enable the accurate determination of the relative position of the timing screw.

The fixing together of the balance rim and balance wheel cross member or members made of different materials may preferably be integrally accomplished by use of the appendage assembly which may serve as both timing and poising appendages and fastening agents of the two material elements to be joined (11).

The Balance wheel rim may be moulded and integrate complete appendage masses (5), or seatings or settings (15) for the insertion of the appendage mass, whereupon the introduction of the radial timing screw through the seating or setting wall, makes captive the appendage mass (16).

Regarding the configuration of the balance wheel assembly.
The balance wheel (8),(9) may be made separately from the balance staff (17). It may be made integrally with the balance staff (20) which itself may be made integrally with the impulse pin (17),(19). The whole may be made in its entirety, or be made integrally with the balance staff (17) allowing for a different material core (18) of similar diameter to the balance pivots to pass through and be fastened in the central axis of rotation or to be integrated and fastened into the upper and

lowermost ends of the balance staff to act as high performance friction relieving pivots made of steel, tungsten , ceramic, composite, diamond especially when used in conjunction with the most suitable chosen friction relieving bearing surfaces made of steel, tungsten, ceramic, diamond, teflon or composite.

The balance is preferably made of a moulded suitable composite or ceramic or ceramic feedstock material or ceramic tape casting material or ceramic powder or micropowder, which in their green state (non fused state) allows for the integration and fixing of a separate balance staff of another material (18), or is made from a one-piece moulding of the balance wheel and cross member and the balance staff together (20), or the integral moulding of the balance wheel crossmember and staff together, upon which is fixed the balance rim of another material or the same material of different phase or texture.

The balance spring of flat archemides form or helicoid form, both forms preferably integrating terminal curves as are known in the art, may preferably be made of ceramic or ceramic composite material.

In the case of the same or different materials it is expedient for the balance staff and balance spring to be integrally moulded and pyrolised, sintered or partially sintered, carbonised or cured, in a controlled manner prior to being fitted to the balance wheel. Further heat treatment or curing by heat or electron or x-ray, ultra-violet or microwave or laser beam may preferably take place for either or both the assembly of the components, or the adjusting of their thermal and or elastic characteristics.

Where the ceramic balance staff, spring and cross member are made as one, then the balance wheel material rim is later fixed in place by compatible means.

In the case where two different ceramics are used they are preferably precision moulded from 'high volume ceramic' preparation, heat treated by pyrolisis or sintered or carbonised or a combination of these and assembled for further heat treatment or the two elements united in the green state and preferably receive full or partial heat treatment together in the assembled state. The precision moulding of the ceramic preparation preferably requires high pressure injection and or compression and or uniaxial, isostatic or hydrostatic pressing with or without heat, or is reaction bonded.

The oscillator system composed of balance wheel, balance staff and balance spring of the same or different preferably ceramic materials, may be assembled after ambient temperature hardening of volatile binding agents preferably prior to heat treatment such that the separate elements are bonded in their correct relative relationship in the chosen heat treatment process. So a ceramic balance staff may be fixed to a ceramic balance spring or other material balance spring at this stage by the appropriate bonding means.

Where the ceramic balance spring is made separately by precision extrusion it is expedient that the cross head or heads, and extruder nozzles or dies preferably but not exclusively allowing for round , square , rectangular or oval cross-section of the extruded material, should be in the vertical direction allowing downward flow of the material onto the receiving plate, die or former or mandrel which is enabled preferably to describe a spiral and terminal curve form such

that the extruded material is laid onto or into the receiving plate or former or mandrel and is obliged to adopt the said form.

Where the extruded material is wound onto a conical channelled or non-channelled heated mandrel it is expedient that partial curing or hardening of the material should take place before its release and the forming of such terminal curve as may be required.

Where the ceramic spring is made by the micro tape-casting process, the ceramic material is preferably laid into or wound onto a stationary or rotating mandrel former or die, preferably partially cured or heat treated, and then further shaped to aquire its final form and then fully cured or heat treated.

Where the balance rim or the spring is made from continuous fibres the prefered method of fabrication is by pultrusion of rovings or tow of 'Pre-preg'(continuous fibre material pre-impregnated with a matrix phase) which is preferably partially cured as it passes through a heated die of any cross-section before being mandrel wound or laid or wound into or onto a former.

It is preferable that such releasing agent as is necessary such as PTFE (Polytetraflouroethylene), FEP (Flourinated Ethylene Propylene Copolymer) or ETFE (Ethylene-Tetraflouroethylene Copolymer) in solid material or vapourised particle form is applied to the mandrels or formers for the expedient release or separation of the components or parts of the components during the fabrication process.

Where the fabrication of the continuous fibre balance rim or continuous fibre balance spring or the ceramic fibre or plain

ceramic rim or ceramic spring is accomplished by the winding of preferably 'Pre-preg' or tape casting material sheet around a cylindrical former with or without the use of an interlayer releasing agent spacing sheet, it is preferable after full or partial curing or heat treatment that the so formed cylindrically shaped roll composed of as many continuously rolled layers as may be required by winding of a continuous sheet of the chosen material around the cylindrical mandrel is subsequently sliced at intervals in the axis perpendicular to the cylinder's rotational axis, thus producing rims or spirals. The method of cutting may preferably be by mechanical, electrical or chemical means, or by beam treatment means, of any wavelength of the spectrum, including cooled non-CO_2 laser cutting techniques and processes.

The interspacing material which is employed for the separation of the successive layers of the multi-layered roll may preferably be removed by mechanical electrical or chemical treatment or by beam treatment means, of any wavelength of the spectrum.

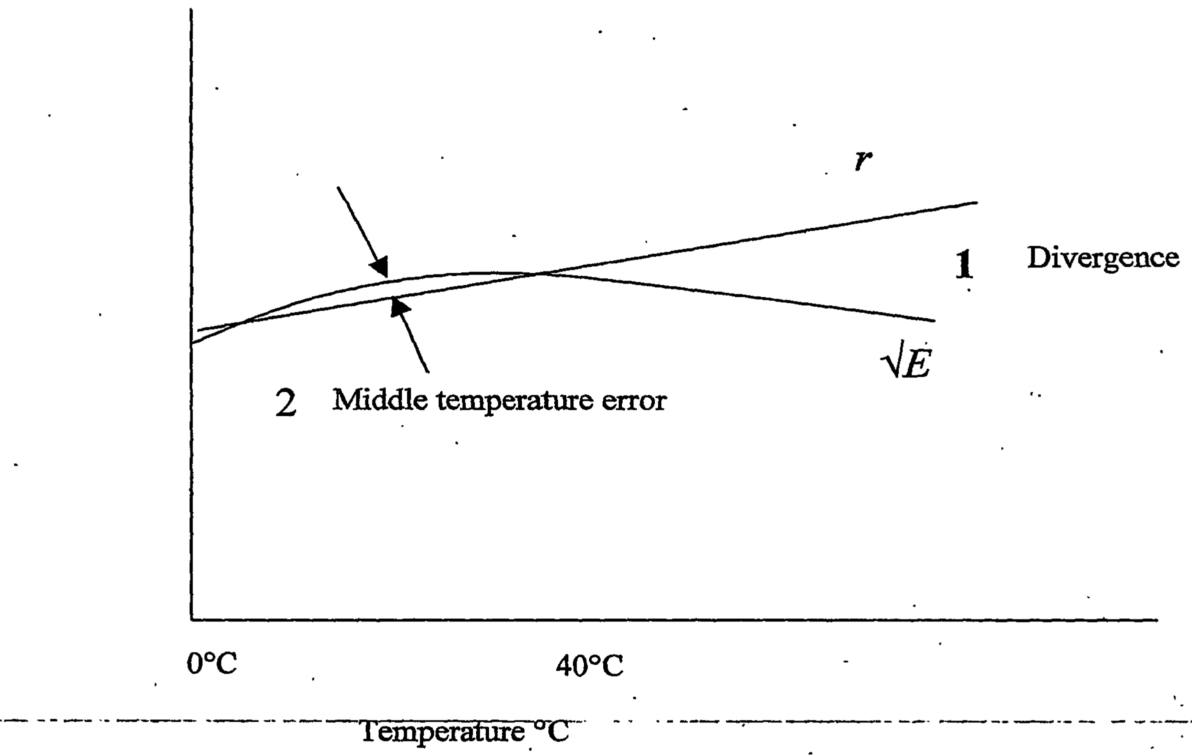

Figure 1.

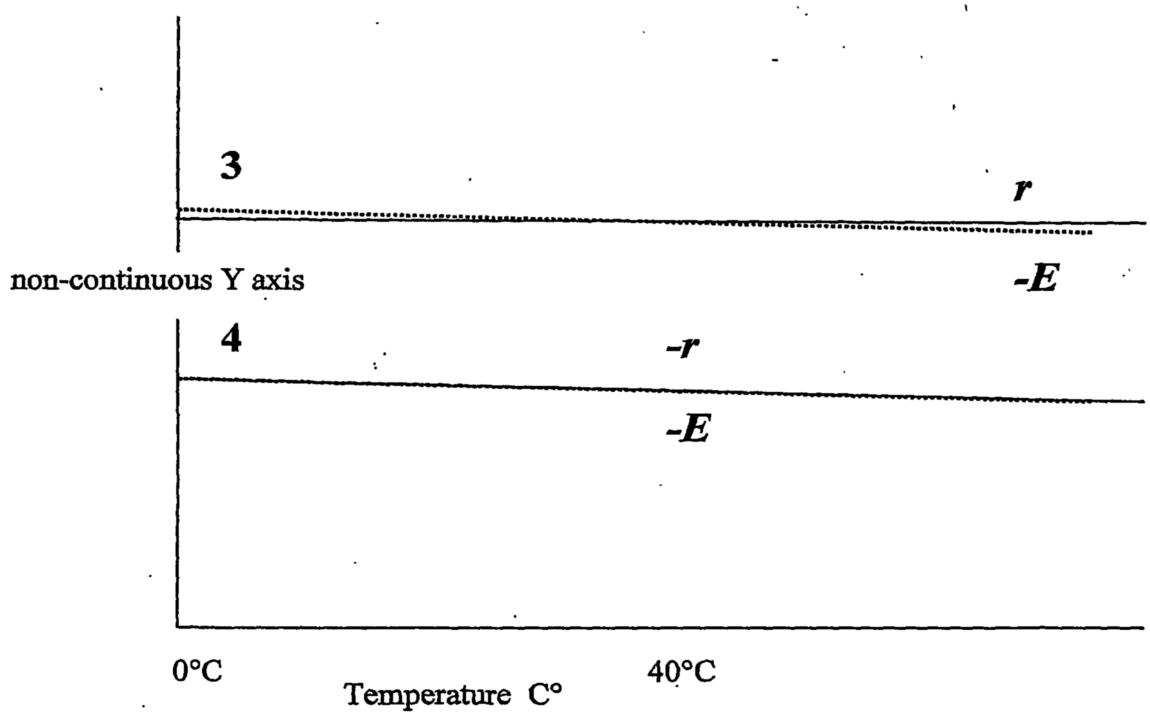

Figure 2.

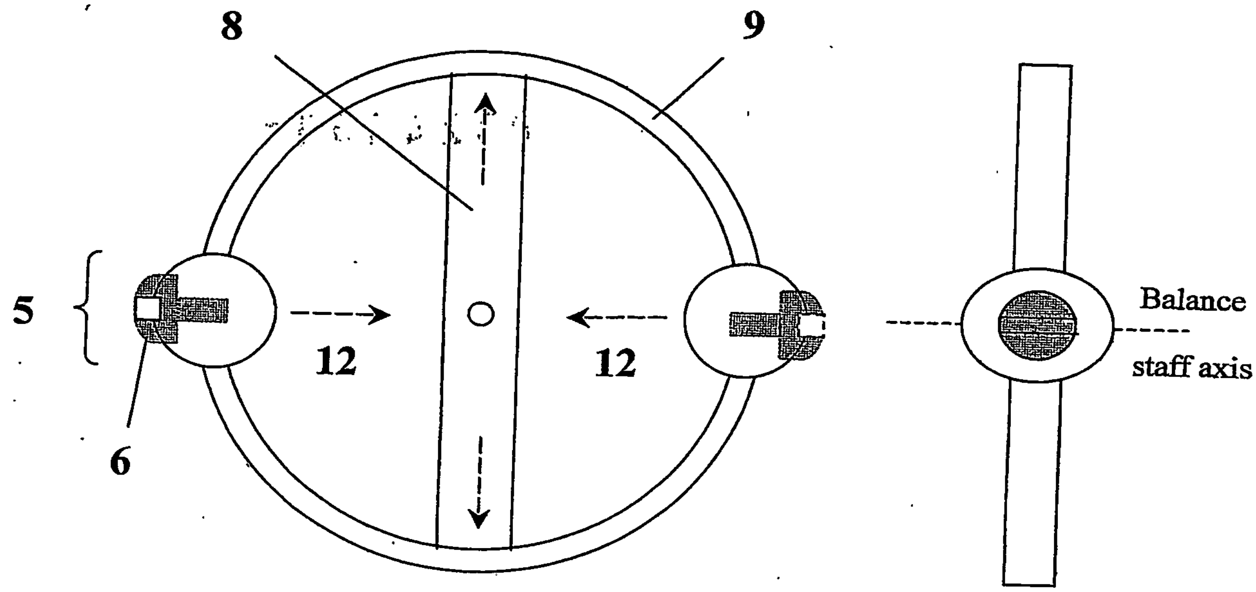

Figure 3.

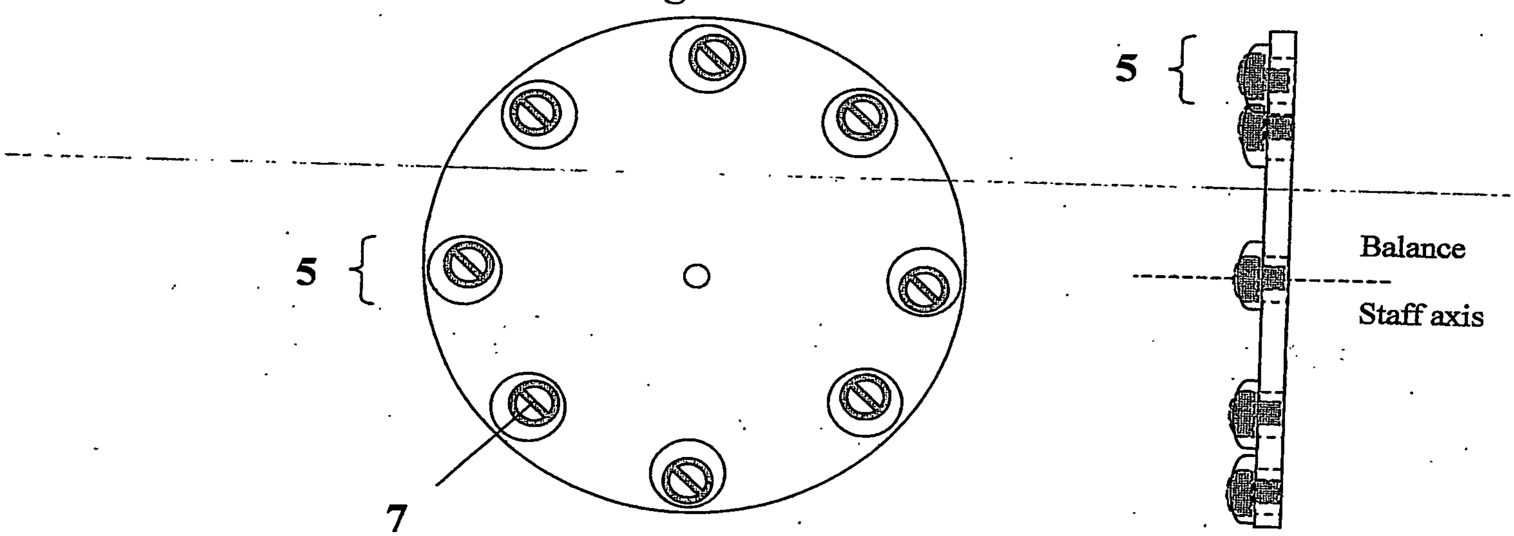

Figure 4.

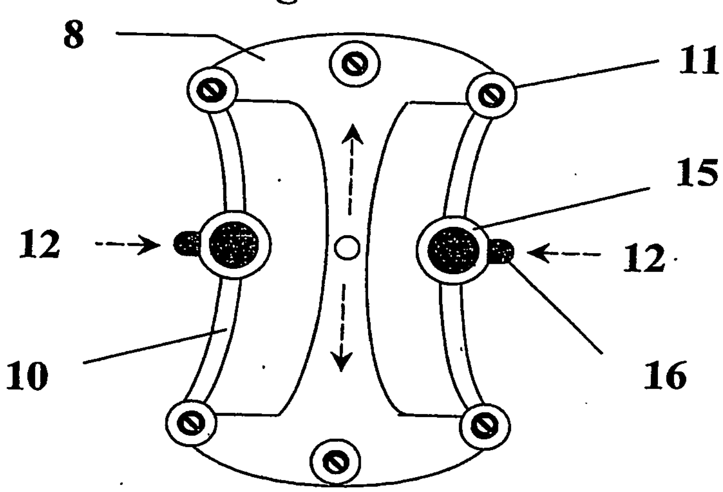

Figure 5.

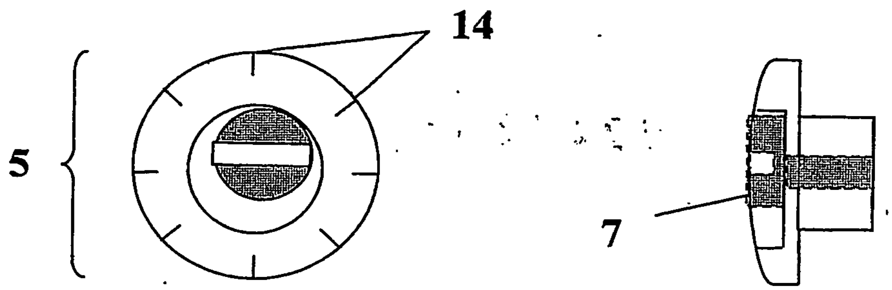

Figure 6.

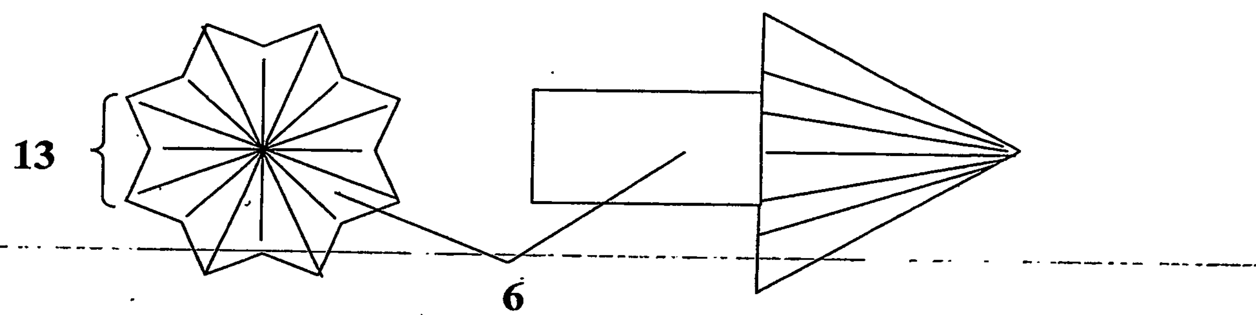

Figure 7.

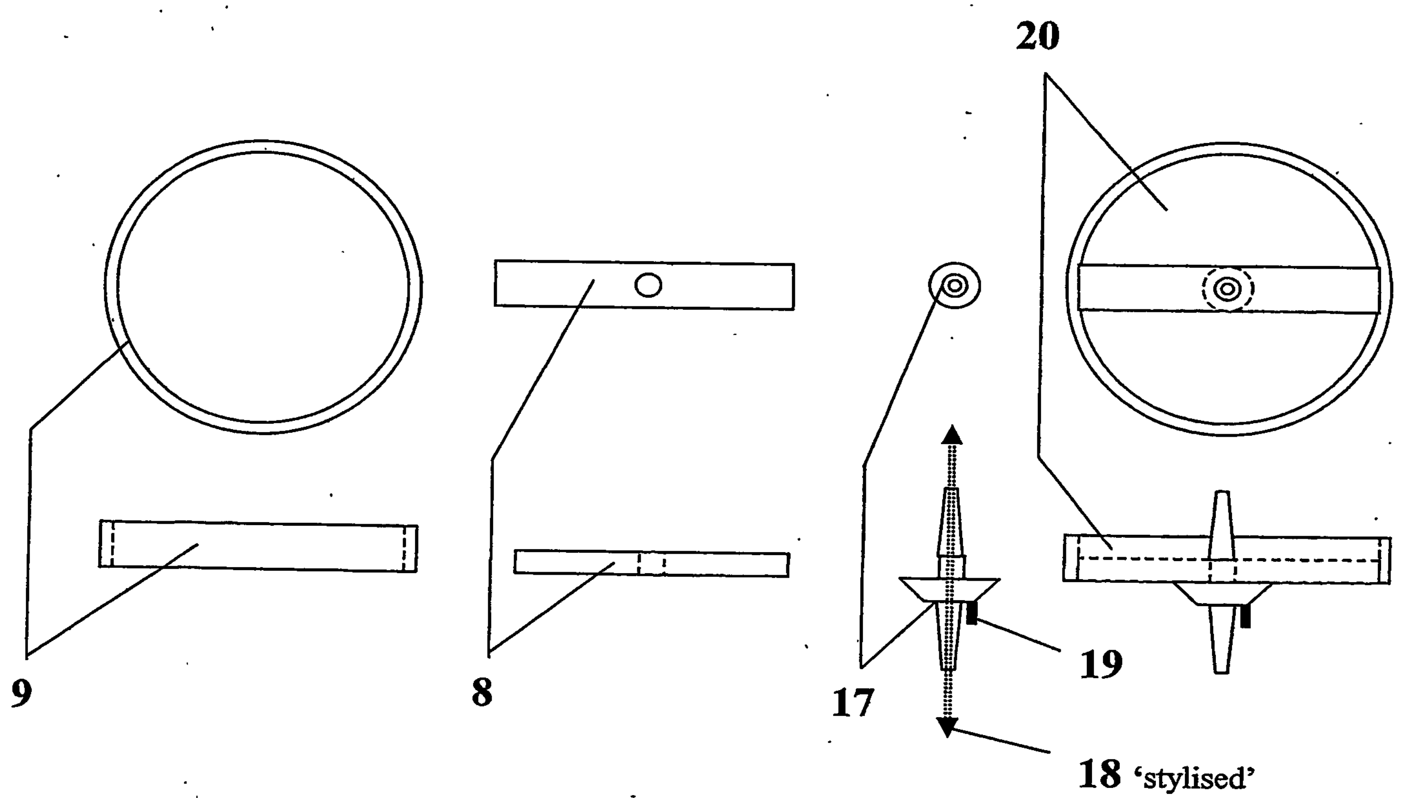

Figure 8.